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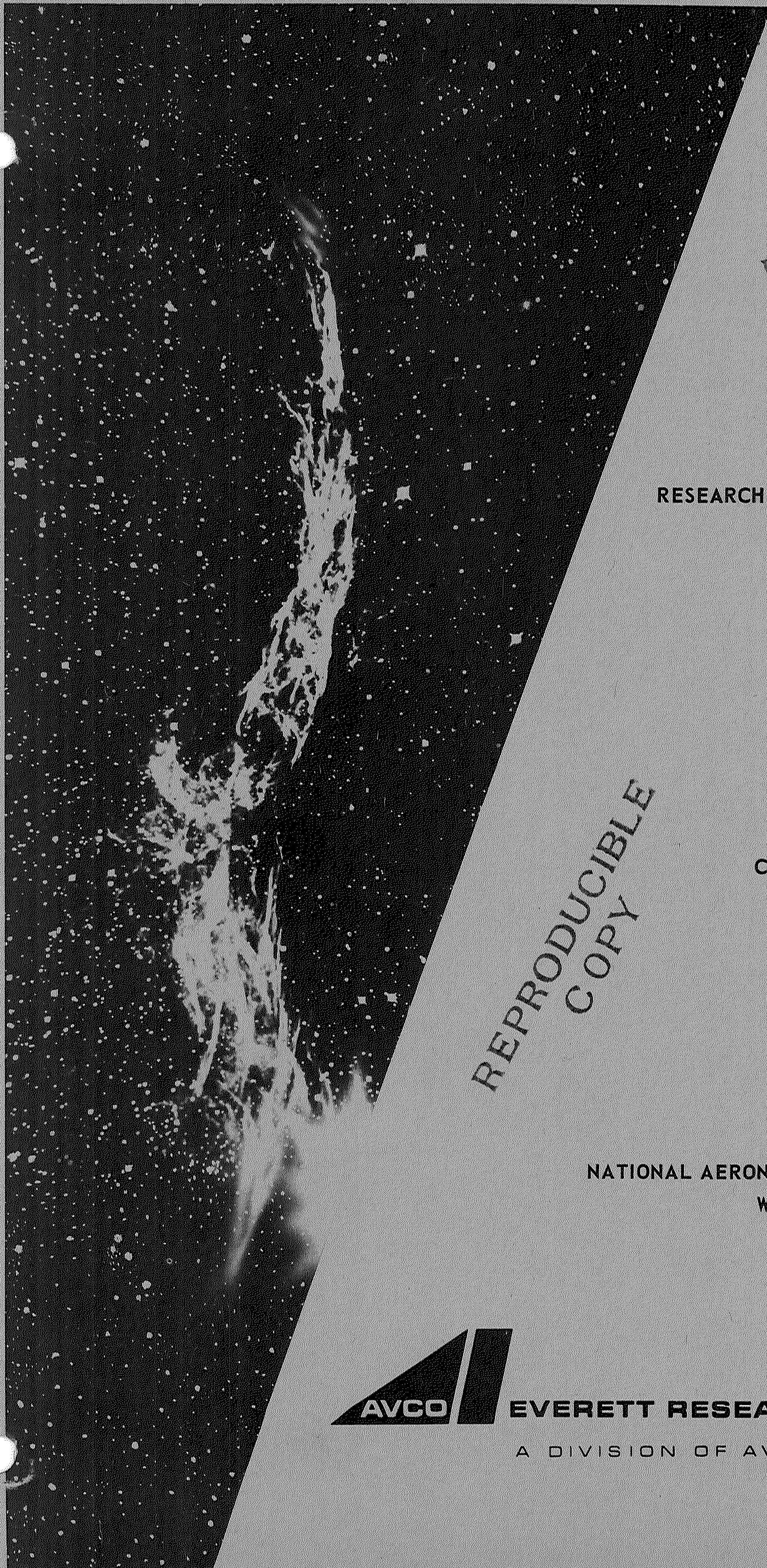
NASA CR-121437



RESEARCH PROGRAM IN PLASMA PHYSICS
FINAL REPORT

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MARCH 1971
Contract No. NASW-2040

prepared for
HEADQUARTERS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 02456

EVERETT RESEARCH LABORATORY
A DIVISION OF AVCO CORPORATION

RESEARCH PROGRAM IN PLASMA PHYSICS

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AVCO EVERETT RESEARCH LABORATORY
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Everett, Massachusetts

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ABSTRACT

Significant progress has been made during this past year in the areas of the two tasks - Collisionless Shock Waves and Barium Cloud Dynamics. A review paper entitled "Collisionless Shocks in Plasmas" has been prepared and published in the Annual Review of Fluid Mechanics, Vol. III, 1971. Several factors which influence the linear stability of barium ion clouds have been investigated including the stability as a function of position around the cloud, and the stabilization provided by the presence of a conducting E-region. Some analytic work on the non-linear equations has also provided some insight into the steepening of the backside of barium ion clouds and the development of magnetic-field-aligned sheets hanging back from the ion cloud in the direction of the neutral cloud. Papers and talks prepared with support of Contract NASW-2040 are listed.

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I. SUMMARY OF WORK PERFORMED

Work under this contract during the past year has progressed both in Task A - Collisionless Shock Waves, and Task B - Barium Cloud Dynamics. A summary of the scope of this progress is given below. The principle results of this research are contained in the two reports "Plasma Cloud Striations" (Linson, 1970a) and "Collisionless Shocks in Plasmas" (Friedman et al., 1970) which are included with this final report. It is expected that research under both of these general task areas will continue under a continuation of this contract and presently unfinished portions of this research will be published.

TASK A - Collisionless Shock Waves

The primary effort under this task was the preparation of a review paper entitled "Collisionless Shocks in Plasmas" which has been published in the Annual Review of Fluid Mechanics, Volume III. This paper (Friedman et al., 1971) was prepared by Lewis M. Linson and Herbert W. Friedman with the assistance of Harry E. Petschek and Richard M. Patrick.

The scope of this paper is to present a review of experimental and theoretical work on shock waves in plasmas where classical collisions are unimportant. The role of dissipation and dispersion in determining shock structure is described and several mechanisms which can provide the required dissipation in collisionless plasmas are discussed. Observations of collisionless shocks produced in laboratory experiments as well as the Earth's bow shock occurring naturally in space are described. Criteria are given when a shock may be considered thin so as to be treated as a discontinuity for flow field calculations. Experimental and theoretical areas where more work is needed are pointed out.

The principal conclusions of this research effort are contained in the summary of this paper which we reproduce here.

> We have seen that shock waves exist in an ionized fluid flowing at super-Alfvenic speeds with a scale length much shorter than the collisional mean free path. A primary goal of collisionless shock research is to determine for what conditions shocks are thin and thus appear as a discontinuity in the fluid description of the flow. For low Mach number, low β, perpendicular shocks, the shocks are very thin, of the order $10\,R_e = 10c/\omega_{pe}$ whereas for all other conditions, i. e., higher Mach number, β, and/or oblique propagation, the shock is thicker, on the order of $R_i = c/\omega_{pi}$. Since the ratio of R_i to R_e is just the square root of the mass ratio, the thicker shocks are only

four times the thinner shocks for hydrogen. For moderate Mach number, the quantity R_i is comparable to the ion gyro radius (based upon flow velocity) since the ion gyro radius $= M_A R_i$. Thus practically speaking, the thickness of collisionless shocks is always comparable to or less than the ion gyro radius. For flow scales which are large compared to the ion gyro radius, a fluid description is valid for the overall flow and the shock can be treated as a discontinuity in the collisionless fluid. Investigation of the shock structure on the other hand, requires a full kinetic description taking into account various turbulent dissipation mechanisms.

The dissipation which must be present in the shock structure in order to satisfy the Rankine-Hugoniot conditions arises from the interactions of the particles with turbulent waves which are generated and amplified in the shock. For low Mach numbers, dispersion effects determine the initial gradients in the shock while dissipation fixes the total shock thickness. At high Mach numbers, dispersion is unimportant and dissipation alone determines the shock structure.

Three types of turbulent dissipation have been observed and progress has been made on understanding two of them. For perpendicular, low β shocks below the critical Mach number M^*, ion acoustic waves are driven unstable by transverse currents and the resulting turbulence scatters and heats electrons. This anomalous resistivity is sufficient to account for the required dissipation. At Mach numbers greater than M^*, ions are heated as a result of a viscous-like mechanism which is neither well documented nor well understood. For oblique shocks, a turbulent spectrum of whistler waves is observed in the shock front which appears to have a sufficient amplitude to scatter the ions an amount necessary to account for the required dissipation. Hence, for oblique and high Mach number perpendicular shocks, ions are heated directly in the shock.

More work is needed to obtain a better understanding of the structure of collisionless shocks. Laboratory experiments could provide detailed measurements of the turbulence which occurs in the shock front. Theoretical work, which has been guided in the past by experimental observation, should progress to the point where critical tests of theoretical ideas can be suggested. As a result, experiments which explore the dependence of the shock thickness and structure on various parameters e. g. , m_e/m_i and ω_{ce}/ω_{pe}, would be useful. As examples of more detailed comparisons of experiment and theory which should become more prevalent in the future we cite the comparison made by Daughney et al. (1970) with the predicted spectrum of Kadomtsev (1965), and the comparison of the theoretically predicted shock thickness made by Krall and Book (1969) with the results obtained in several different experiments.

The most significant advance in the study of the Earth's bow shock will come from multiple satellite probes which allow the separation of spatial from temporal variations and the determination of the polarizations of the turbulent fields and wave vectors. Only then can meaningful measurements be made of the shock thickness and turbulent wavelengths so that Doppler shifts can be inferred.

The mechanism which leads to the anomalous ion viscosity in perpendicular shocks for Mach number greater than M^* still remains to be explained. In addition, more theoretical work is needed in order to explain the ion heating which occurs in oblique shocks due to whistler wave turbulence. At high Mach number ($M_A \sim 5 - 10$) the relative importance of (electromagnetic) whistler wave turbulence and fine scale (electrostatic) ion acoustic wave turbulence in providing dissipation needs to be critically assessed. Furthermore, the area of very high Alfven Mach number where the energy contained in the magnetic field is insignificant as compared to kinetic energy is becoming more relevant as the possibility of forming electrostatic shocks, a topic not discussed in this review, is being actively investigated. The next few years should provide a considerable increase in our understanding of the above phenomena.

The above summary represents a fair assessment of the current status of understanding of the structure of collisionless shock waves. It provides the basis for formulating future work. We shall investigate the role of electrostatic and electromagnetic instabilities in providing the anomalous ion viscosity which must be present in the higher Mach number shocks.

TASK B - Barium Cloud Dynamics

Progress in this area has been significant. The paper "Formation of Striations in Ionospheric Plasma Clouds" (Linson and Workman, 1970a) is the first and, to date, only paper in print describing the origin of magnetic field aligned striations in barium ion clouds. We have called the relevant instability the gradient-drift instability. The principal points of this paper were; a) the backside of ion clouds (the side closest to the neutral cloud) is unstable to the formation of striations; b) the growth rate at high altitudes (greater than 140 km) scales as U_o/d where $\underline{U}_o = \underline{V}_{ion} - \underline{V}_{neutral}$ and $d = |\nabla \ell nN|^{-1}$ where N is the plasma density. Both of these points are in agreement with observations. This paper sets forth the basic mechanism responsible for the formation of striations. This area of research is currently very active because there are a number of important factors which modify the basic treatment and because the mechanism is important for natural ionospheric phenomena. The results of this paper were presented at the annual meeting of the Division of Plasma Physics of the American Physical Society in Los Angeles (Linson and Workman, 1969).

One of the first generalizations of the above work was reported by Linson and Workman (1970b) at the annual AGU Meeting. This investigation considered the stability of various edges around the barium cloud by considering different orientations of the density gradient with respect to the velocity $\underline{U}_o$. The conclusions were that the dependence of the growth rate on the position around the cloud depends on the parameter $\Omega\tau$ (Ω is the ion gyrofrequency and τ is the ion-neutral collision time) and that a complete analysis should allow a range of orientations of the wave-vector $\underline{k}$ with respect to the edge. It was found that the growth rate maximizes near the back edge validating the earlier analysis.

We have also considered the effect of the E-region conductivity on the stability of barium ion clouds. A simple model shows that the growth rate is reduced by a factor $(1 + \Sigma_p^E/\Sigma_p^C)^{-1}$ due to the presence of a conducting E-region. Σ_p^E and Σ_p^C are the height integrated Pedersen conductivities in the E-region and the ion cloud respectively. This result indicates that a low density ion cloud can be stabilized by a highly conducting E-region. This result is in agreement with the appropriate limit of a more complete treatment by Volk and Haerendel (1971) to be published. We have also shown that inductive effects are unimportant for determining stability inspite of the large current loop in the ionosphere which might be hundreds of kilometers long.

The next major improvement in the linear stability theory was made by including electron collisions in the analysis. Electron collisions allow the plasma to diffuse across magnetic field lines thus stabilizing the shorter wavelengths giving rise to a minimum unstable wavelength. This generalization allowed the theory to be applied throughout the altitude range 80 to 250 km. The main results were that the growth rate maximizes at around 98 km (for constant applied electric field) but still has a rather broad range of unstable wavelengths. The results of this analysis were presented at the Upper Atmospheric Currents and Electric Fields Symposium (Linson, 1970a, 1970b) in Boulder in August 1970. It was pointed out that these results have important implications for auroral curtains and for ion clouds created in and below the E-region. This topic has been the subject of great interest. Unwin and Knox (1970) reported on observations of the gradient-drift instability in radio aurora, and Davis and Althouse (1970) reported on the observations of this instability in artificial ion clouds created between 85 and 105 km. These observations are in good agreement with the above theory.

Considerable progress has also been made in the non-linear theory of barium ion cloud dynamics. An analytic solution of the non-linear equations which govern the growth of striations has been found. The results were presented at the annual meeting of the Division of Plasma Physics of the American Physical Society in Washington, D. C. in November, (Linson, 1970c). The non-linear solution shows that small perturbations on the backside of ion clouds develop into long, field-aligned sheets hanging back from the ion cloud in the direction of the neutral cloud. The analytic solution is valid into the fully non-linear regime. This theoretical interpretation is in excellent agreement with recent observations of barium ion clouds viewed nearly up the magnetic field lines (Rosenberg, 1971). In a paper presented at the annual AGU Meeting in Washington, D. C. in April, a quantitative comparison between theory and these observations was made (Linson, 1971). This work needs to be continued and upgraded.

We have also begun an analytic treatment of the non-linear equations which govern the deformation of barium ion clouds prior to the time that striations occur. This work shows the steepening on the backside of barium ion clouds which has consistently been observed to occur. This analytic treatment also seems to provide an explanation as to why the dimension transverse to the magnetic field seems to increase in width far faster than would be permitted by classical diffusion, even with an electron short across the magnetic field lines. It also shows promise of providing an explanation for the appearance of a sharp density gradient on one side of the cloud when viewed from two or more widely divergent angles. This analysis is very promising and also needs more work.

REFERENCES

Daughney, C. C., L. S. Holmes, and J. W. M. Paul, Phys. Rev. Lett., 25, 497-499, 1970.

Davis, J. R., and E. L. Althouse, "Instabilities Observed by Decameter Radar in Lower E-Layer Alkali Plasma Clouds and Their Implications Regarding Sporadic-E", presented to the Upper Atmospheric Currents and Electric Fields Symposium, Boulder, Colorado, Aug. 17-21, 1970.

Friedman, H. W., L. M. Linson, R. M. Patrick, and H. E. Petschek, "Collisionless Shocks in Plasmas," Avco Everett Research Laboratory Research Report 363, December 1970.

Friedman, H. W., L. M. Linson, R. M. Patrick, and H. E. Petschek, "Collisionless Shocks in Plasmas," Ann. Rev. Fluid. Mech., 3, 63-88, 1971.

Kadomtsev, B. B., Plasma Turbulence Academic Press, London, p. 149, 1965.

Krall, N. A., and D. Book, Phys. Rev. Lett., 23, 574-576, 1969.

Linson, L. M., "Plasma Cloud Striations," Avco Everett Research Laboratory AMP 315, September 1970a.

Linson, L. M., "Plasma Cloud Striations between 80 and 250 km," presented to the Upper Atmospheric Currents and Electric Fields Symposium, Boulder, Colorado, Aug. 17-21, 1970b.

Linson, L. M., "Analytic Solution of Non-Linear Equations Governing Striation Development in Ionospheric Plasma Clouds," Bull. Am. Phys. Soc., 15, 1471, 1970c.

Linson, L. M., "Non-Linear Barium Ion Cloud Dynamics," EOS, Trans., Am. Geophys. Union, 52, 298, 1971.

Linson, L. M., and J. B. Workman, "Formation of Striations in Ionospheric Plasma Clouds," Bull. Am. Phys. Soc., 14, 1039, 1969.

Linson, L. M., and J. B. Workman, "Formation of Striations in Ionospheric Plasma Clouds," J. Geophys. Res., 75, 3211, 1970a.

Linson, L. M., and J. B. Workman, "Formation of Striations in Ionospheric Barium Ion Clouds," EOS, Trans., Am. Geophys. Union, 51, 396, 1970b.

Rosenberg, N. W., "Observation of Striation Onset in a Barium Release," EOS, Trans., Am. Geophys. Union, 52, 298, 1971.

Unwin, R. S., and F. B. Knox, "Radio Aurora and Electric Fields," presented to the Upper Atmospheric Currents and Electric Fields Symposium, Boulder, Colorado, Aug. 17-21, 1970.

Volk, H. J., and G. Haerendel, "Striations in Ionospheric Ion Clouds, Part I," to be published in J. Geophys. Res., 1971.

II. FORMAL ACTIVITIES

A. Papers Prepared with Support of Contract NASW-2040

Linson, L. M., "Plasma Cloud Striations between 80 and 250 km," presented to the Upper Atmospheric Currents and Electric Fields Symposium, Boulder, Colorado, Aug. 17-21, 1970.

Linson, L. M., "Plasma Cloud Striations," Avco Everett Research Laboratory AMP 315, September 1970.

Friedman, H. W., L. M. Linson, R. M. Patrick, and H. E. Petschek, "Collisionless Shocks in Plasmas," Avco Everett Research Laboratory Research Report 363, December 1970.

Friedman, H. W., L. M. Linson, R. M. Patrick, and H. E. Petschek, "Collisionless Shocks in Plasmas," Ann. Rev. Fluid Mech., 3, 63-88, 1971.

B. Talks Prepared with Support of Contract NASW-2040

Linson, L. M., and J. B. Workman, "Formation of Striations in Ionospheric Plasma Clouds," Bull. Am. Phys. Soc., 14, 1039, 1969.

Linson, L. M., and J. B. Workman, "Formation of Striations in Ionospheric Barium Ion Clouds," EOS, Trans., Am. Geophys. Union, 51, 396, 1970.

Linson, L. M., "Plasma Cloud Striations between 80 and 250 km," presented to the Upper Atmospheric Currents and Electric Fields Symposium, Boulder, Colorado, Aug. 17-21, 1970.

Linson, L. M., "Analytic Solution of Non-Linear Equations Governing Striation Development in Ionospheric Plasma Clouds," Bull. Am. Phys. Soc., 15, 1471, 1970.

Linson, L. M., "Non-Linear Barium Ion Cloud Dynamics," EOS, Trans., Am. Geophys. Union, 52, 298, 1971.

C. Abstracts of Papers and Talks

Friedman, H. W., L. M. Linson, R. M. Patrick, and H. E. Petschek, "Collisionless Shocks in Plasmas," Avco Everett Research Laboratory Research Report 363, December 1970.

Linson, Lewis M., and Joseph B. Workman, "Formation of Striations in Ionospheric Barium Ion Clouds," presented at the 51st Annual Meeting of the American Geophysical Union, Washington, D. C., April 20-24, 1970.

Linson, Lewis M., "Plasma Cloud Striations Between 80 and 250 km," presented at the 1970 Symposium on Upper Atmospheric Currents and Electric Fields, Boulder, Colorado, August 17-21, 1970.

Linson, Lewis M., "Plasma Cloud Striations," Avco Everett Research Laboratory AMP 315, September 1970.

Linson, Lewis M., "Analytic Solution of Non-Linear Equations Governing Striation Development in Ionospheric Plasma Clouds," presented at the Annual Meeting of the Division of Plasma Physics of the American Physical Society, Washington, D. C., November 4-7, 1970.

Linson, Lewis M., "Non-Linear Barium Ion Cloud Dynamics," presented at the 52nd Annual Meeting of the American Geophysical Union, Washington, D. C., April 12-16, 1971.

COLLISIONLESS SHOCKS IN PLASMAS*

H. W. Friedman, L. M. Linson, R. M. Patrick
and H. E. Petschek

ABSTRACT

A review of experimental and theoretical work on shock waves in plasmas where classical collisions are unimportant is presented. The role of dissipation and dispersion in determining shock structure is described and several mechanisms which can provide the required dissipation in collisionless plasmas are discussed. Observations of collisionless shocks produced in laboratory experiments as well as the Earth's bow shock occurring naturally in space are described. Criteria are given when a shock may be considered thin so as to be treated as a discontinuity for flow field calculations. Experimental and theoretical areas where more work is needed are pointed out.

*Avco Everett Research Laboratory Research Report 363, December 1970.

FORMATION OF STRIATIONS IN IONOSPHERIC BARIUM ION CLOUDS*

Lewis M. Linson and Joseph B. Workman

ABSTRACT

It is suggested that a low frequency "gradient drift" instability may be important for the formation of striations in barium ion clouds released in the ionosphere above the E-layer. The theory predicts that generally the trailing edge (with respect to the neutrals) of the plasma cloud will be unstable while the leading edge is stable, in qualitative agreement with observations. The growth rate exhibits a broad maximum as a function of wavelength. The minimum growth time is of order d/U_0 where d is the typical density gradient length and U_0 is the velocity of the cloud with respect to neutrals. Short wavelengths are stabilized by diffusion. Predicted growth times varying from seconds in the auroral zone at high latitude to minutes at midlatitudes are also in agreement with observation. Wavelengths of waves with zero phase velocity are found to be given approximately by $\lambda = 2\pi d$ which can be verified by optical observations. The variation of the growth rate as a function of altitude, wave number, and orientation around the plasma cloud has been examined.

*Presented at the 51st Annual Meeting of the American Geophysical Union, Washington, D. C., April 20-24, 1970.

PLASMA CLOUD STRIATIONS BETWEEN 80 AND 250 km*

Lewis M. Linson

ABSTRACT

The present paper represents a continuation of investigations into the applicability of the gradient drift instability to ionospheric phenomena. A number of authors (Maeda, Tsuda, and Maeda, 1963; Tsuda, Sato and Maeda, 1966; Whitehead, 1967; Whitehead, 1968; Reid, 1968; Tsuda, Sato, and Matsushito, 1969; Chimonas, 1969; Cunnold 1969) have applied this low frequency instability (sometimes called $\underline{E} \times \underline{B}$ or crossed field instability) to explain naturally occurring irregularities due to the vertical ionospheric density gradient. It has recently been suggested (Linson and Workman, 1970) that this same gradient drift instability is responsible for the formation of striations in artificial ion clouds released in the lower F region. The purpose of the present paper is two-fold. First, we examine the implications of the model used in all of the above calculations. Second, we extend the previous stability analysis (Linson and Workman, 1970) to apply to magnetic field aligned plasma clouds (either artificially or naturally produced) throughout the E and lower F region.

The analysis which is described in this paper is limited to uniform columns of ionization parallel to the magnetic field $\underline{B}$, but does pay careful attention to the requirement of a physically realistic, self consistent equilibrium solution perpendicular to $\underline{B}$ about which to make perturbations for a stability analysis. In particular we require that unperturbed ion and electron velocities far from the cloud be constant and that proper accounting be made of any current which flows out of the edge of the plasma cloud. We show that when currents are required to flow only transverse to $\underline{B}$ there is no steady state, non-uniform equilibrium distribution of ion density which goes to a constant at large distances (even when electron collisions are neglected so that no diffusion is allowed). A two-dimensional density enhancement tends to deform resulting in an increase in the density gradient on the backside of barium ion clouds in agreement with observations.

The only one-dimensional density distribution consistent with constant, unperturbed ion and electron velocities is an exponential variation and therefore can only describe an edge of the plasma cloud. The stability of this zero'th order model is examined throughout the E and lower F regions under the restrictive assumption that $\underline{J} \cdot \nabla N = 0$. A simple analytic dispersion relation is obtained which shows that maximum growth rates occur around

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*Presented at the 1970 Symposium on Upper Atmospheric Currents and Electric Fields, Boulder, Colorado, August 17-21, 1970.

98 km for wavelengths of order 1/20 the density gradient length and smaller growth rates exhibit a broad maximum at long wavelengths above 130 km. The maximum unstable perturbations around 98 km altitude propagate preferentially in the direction of the density gradient while at higher altitudes they propagate preferentially perpendicular to the density gradient. For high altitude plasma clouds, we relax the restriction $\underline{J} \cdot \nabla N = 0$ by allowing electrons to flow freely along $\underline{B}$ for two cases. By relaxing the restriction in first order, the conducting E-region is found to increase the stability of the cloud against formation of striations while relaxing the restriction in zero'th order corresponds to investigating the stability of different portions of the plasma cloud. Directions for future work will be indicated.

PLASMA CLOUD STRIATIONS*

Lewis M. Linson

ABSTRACT

The gradient drift instability has been extended by including electron collisions to apply to plasma clouds (either artificially or naturally produced) throughout the E and lower F region. The need for a self-consistent equilibrium configuration with proper accounting of any current which flows out the edge of the plasma cloud is emphasized. A one-dimensional slab model representing the back edge of a plasma cloud is used to obtain a simple, analytic, mathematically rigorous dispersion relation describing the formation of striations. The resulting growth rate scales as the ratio of the electric field to the density gradient length and can range from times shorter than one tenth of a second in the auroral zone E-region to times as long as minutes for mid-latitude high-altitude barium releases. The broad spectrum of unstable waves can range from meters to hundreds of meters in the auroral zone E-region and from tens to thousands of meters for mid-latitude barium releases. These results suggest that auroral curtains and mid-latitude plasma releases in the E-region will striate rapidly.

*Avco Everett Research Laboratory AMP 315, September 1970.

ANALYTIC SOLUTION OF NON-LINEAR EQUATIONS GOVERNING STRIATION DEVELOPMENT IN IONOSPHERIC PLASMA CLOUDS*

Lewis M. Linson

ABSTRACT

The two-fluid equations which describe the formation of striations** in high-altitude barium clouds can be reduced to a simple, coupled pair of non-linear differential equations. These equations show: 1) there is no two-dimensional configuration of plasma cloud density in the plane perpendicular to $\underline{B}$ which is time independent and 2) the backside of plasma clouds must steepen in agreement with observations. The non-linear development of striations on the backside of a plasma cloud has been obtained with the use of a one-dimensional plasma slab model as was used in the linear analysis.** The analytic solution for density enhancements or depressions show: 1) striations can develop into long, field aligned sheets extending backwards from a plasma cloud; 2) density depressions grow more rapidly in the non-linear regime than do enhancements; 3) contours of equal electron density do not coincide with ion displacement contours.

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* Presented at the Annual Meeting of the Division of Plasma Physics of the American Physical Society, Washington, D. C., November 4-7, 1970.

**L. M. Linson and J. B. Workman, J. Geophys. Res. 75, 3211 (1970).

NON-LINEAR BARIUM ION CLOUD DYNAMICS*

Lewis M. Linson

ABSTRACT

A simple, coupled pair of non-linear differential equations is shown to be applicable for a description of the dynamics of barium ion clouds released in the lower F-region. Two striking aspects of the observed dynamics are the increase in ion density gradient and the development of magnetic field aligned striations both occurring on the backside of the ion clouds. This theoretical model which assumes negligible diffusion perpendicular to $\underline{B}$ adequately describes these two characteristics. Unique observations by N. W. Rosenberg of a barium ion cloud viewed up the magnetic field lines show that striations develop as field-aligned sheets on the backside of the ion cloud in the direction of the neutral cloud in quantitative agreement with an analytic solution of the non-linear equations. The major points of agreement between this theory and observations are: 1) backside steepening; 2) striation development on the backside of the cloud; 3) striation development at the location of maximum density gradient; 4) striation development as field-aligned sheets; 5) peak densities never increase. A deficiency of this simple model is the lack of a mechanism which determines the striation scale size.

*Presented at the 52nd Annual Meeting of the American Geophysical Union, Washington, D. C., April 12-16, 1971.